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**Keywords:** medium density fiberboard, chicken feather fiber, composite, properties, durability.

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## INTRODUCTION

Chicken feathers are a waste product from the processing of chickens for food. Approximately  $2 \times 10^9$  kg of chicken feather waste is generated in the United States each year (Parkinson 1998). Chicken feather fiber (CFF) offers a large, cheap fiber market as an additive for medium density fiberboard (MDF). Chicken feathers consist of approximately half fiber and half quill (by weight). Both the fiber and quill consist of hydrophobic keratin, a protein with strength similar to that of nylon and with a diameter smaller than that of wood fiber. The quills have commercial applications in shampoo, hair conditioner, hair coloring, and dietary supplements. The fiber is more durable than the quill and has a higher aspect ratio. Finding a high volume, high value use for CFF, which is most commonly land-filled or used for feed protein, would greatly benefit the poultry industry and would represent another source of fiber for the wood industry.

For all phases of the study, wood fiber, consisting primarily of aspen (*Populus* spp.), was obtained from a commercial MDF plant in northern Wisconsin. The CFF was removed from the quills by Featherfiber Corporation (Nixa, Missouri) using a process patented by the USDA Agricultural Research Service (Gasser et al. 1998). The quillfree CFF was shipped to the Forest Products Laboratory in Madison, Wisconsin. A phenol formaldehyde (PF) oriented-strandboard

face resin was applied at 5% by weight to all boards. The PF resin was provided by Dynea Resins, Inc. (Eugene, Oregon).

### **OBJECTIVES**

Our study objective was to study the mechanical and physical properties of MDF panels made from different mixtures of wood fiber and CFF. Our programmatic goals were to determine if CFF has an effect on the properties of composite panels and to determine if CFF could augment or improve selected performance properties of MDF.

The general study was conducted in two phases. The primary objective of Phase I was to evaluate a broad range of wood fiber-CFF (hereafter called MDF-CFF) combinations (Table 1). Panels made with 75%/20% MDF/CFF and 47.5%/47.5% MDF/CFF were compared to control panels made from only wood fibers and only CFF. The experimental panels were bonded with 5% PF resin. Another objective of Phase I was to evaluate the effect of selectively placing all wood fiber or all CFF in either the panel faces or cores. Preliminary results from initial evaluations of combinations using at least 20% CFF were previously reported (Winandy et al 2003).

The objective of Phase II was to evaluate a more precise range of MDF-CFF combinations having less than 25% CFF to determine the threshold or thresholds of CFF required to decrease thickness swelling and increase moisture resistance (Table 2). All-wood controls were compared to a series of MDF-

CFF combinations, from 92.5%/2.5% to 75%/25% MDF/CFF over 2.5% to 5.0% increments.

This paper reviews the entire research program and describes new results from Phase II.

### **PHASE I**

Our preliminary work indicated that some loss in strength and stiffness could be expected for MDF-CFF panels when compared to the properties of all-wood control panels (Winandy et al. 2003). However, the physical properties of MDF-CFF panels also showed a marked improvement in resistance to water-soak absorption and thickness swell compared to that of control panels made with wood fiber only. This result was probably related to the hydrophobic component of amino acids within the keratin in CFF.

In Phase I, two replicate panels were made from each composition, resulting in a total of 12 panels. The panels were 380 by 380 by 12 mm. A PF resin was applied to the wood fiber, CFF, or the combined MDF-CFF furnish in a rotating drum blender. Both the wood fiber and CFF were laid up in various combinations as a mat, as indicated in Table 1 and shown in Figures 1 and 2. Control panels were made with 95% aspen fiber and 5% resin and with 95% CFF and 5% resin. The panels were pressed at 200°C for approximately 240 s. In preliminary tests, that time was found to be long enough to fully cure the PF resin.

After pressing, all panels were weighed and measured for determination of specific gravity. Springback of 12-mm-thick panels after 24-h exposure at 23°C and 65% relative humidity (RH) was also recorded. After springback was measured, panels were cut into specimens for mechanical and physical tests (Table 3). Water-soak absorption and thickness swell were measured 2 h and 24 h from start of test.

Mechanical property tests indicated that addition of CFF to the composites had very little negative effect on internal bond (IB) strength. Modulus of elasticity (MOE) and modulus of rupture (MOR) of the single-layer MDF panel with 20% CFF were similar to that of the panel with only wood fiber (Table 4). The differences in MOE and MOR between the single-layer MDF and the two types of triple-layer panel were probably remnants of processing and not related to an inherent difference between the various composites. When the proportions of wood fiber and CFF were equal, the MDF-CFF panel had superior moisture resistance in a 2-h thickness swell test and a water-soak absorption test. These soak tests indicated that augmenting wood fiber with varying amounts of CFF may provide enhanced resistance to moisture for MDF and other wood composites (Table 4).

Decay tests were conducted using the ASTM D 1413 soil-block method (ASTM 2003a). An equal mixture of CFF and wood fiber imparted some decay resistance against both brown and white rot fungi, as indicated by percentage of weight loss

(Table 5). This effect was further supported by the relatively high decay resistance of MDF with CFF in the face material where the panel was in direct contact with the feeder strip. The CFF-rich faces apparently inhibited some subsequent decay in the wood fiber core. However, we do not consider CFF a bio-efficacious substance. Rather we believe that CFF measurably improved the resistance of the MDF-CFF composite to water absorption (Table 4). This temporary resistance to water absorption in turn resulted in a slower progression of decay in the 12-week ASTM D 1413 soil-block test for the MDF-CFF composite when compared to control panels made with only wood fiber. This benefit of initial slowing of water absorption is probably related to the hydrophobic keratin in CFF.

## **PHASE II**

While the objectives of Phase II called for a modified experimental design (Table 2), except as noted below all material and composite laboratory processing factors and standardized testing procedures (e.g., physical, mechanical, decay, etc.) were identical to those previously described for Phase I.

### **Methods and Materials**

In Phase II, 3 replicate panels of 9 combinations of wood fiber and CFF were made from each tested composition, resulting in a total of 27 panels (Table 2). The panels were

380 by 380 by 12 mm. Control panels were made with 95% aspen fiber and 5% PF resin. No wax was added. In general, the combinations were made by incrementally replacing about 2.5% of wood fiber with CFF, while always using 5% PF resin for bonding. The panels were pressed at a platen temperature of 200°C for approximately 240 s, the time found in preliminary testing to be sufficiently long to fully cure the PF resin. After pressing, panels were weighed and measured for determination of specific gravity. Springback was recorded after 24-h exposure at 23°C and 65% RH, and panels were then cut into specimens for mechanical and physical testing (Table 6). Water-soak absorption and thickness swell were measured at 2 and 24 h from start of test.

An alternating humidity exposure test was developed in Phase II to further investigate the potential for CFF to inhibit moisture absorption. A 50-mm by 50-mm by full-thickness (~12-mm) specimen was monitored during exposure to equilibrium in an alternating humidity environment (vapor only, no direct exposure to liquid moisture). Specimens were placed in a 22°C/50% RH environment and weighed every 7 to 10 days. After equilibrating to the environment (day 17), specimens were moved to a 27°C/90% RH until equilibrated at 41 days, then returned to a 22°C/50% RH environment until equilibrated after 45 days, after which the test was terminated. The objective of the alternating humidity exposure



test was to assess the hygroscopic potential of the MDF-CFF composites to vapor rather than liquid moisture, which was determined using the ASTM D 1037 water-soak absorption/thickness swell test (ASTM 2003b).

## **Results and Discussion**

Overall, single-layer MDF boards with from 0 to 25% CFF had similar MOE and bending strength (MOR) (Table 7). The variability in MOE and MOR was most likely the remnant of processing and our choice of resin system. Internal bond (IB) tests indicated that progressive addition of CFF to MDF resulted in a discernable decrease in IB strength. However, when these results are considered together with the Phase I results (which did not show a similar relationship), the IB effect was also most likely a remnant of processing and choice of resin system. We believe that the quality of the PF resin bond with CFF in these experiments was not as high as could be attained with other resin systems such as MDI, which may be more compatible with the protein binding sites in CFF as opposed to the carbohydrate binding sites in wood.

The Phase I results had indicated that addition of 20% to 50% CFF might restrict moisture absorption. In Phase II, we evaluated three modes of moisture absorption: extended soaking, one-sided contact of dry MDF-CFF to moist soil and/or moist wood (feeder strip) in the 12-week decay test, and pure vapor absorption in alternating RH environments.

The thickness swell and water-soak absorption data shown in Table 8 clearly show that when MDF-CFF panels were immersed in liquid water in a water-soak test, moisture absorption was not noticeably different between various MDF-CFF compositions. The data for the vapor-phase absorption in alternating RH environments are shown in Figure 3. The absolute equilibrium moisture content at any RH among various MDF-CFF combinations seems to exhibit no clearly distinguishable difference in that all of the combinations seem to vary randomly about  $\pm 1\%$  about the general trend. This presumably reflects the potential precision of our method at this stage of development. More importantly, it seems to also indicate that, in a pure vapor-phase mode of exposure, the absorption of moisture into MDF-CFF composites does not exhibit a noticeably different trend (i.e., rate of change) related to the CFF composition as all data lines seem parallel in practical terms.

However, the ASTM D 143 soil-block decay tests indicated some possible benefits from adding proportionately greater levels of CFF to MDF in composite board (Figs. 4 and 5). When exposed for 12 weeks to the white-rot fungus (*Trametes versicolor*), the moisture content of MDF-CFF blocks was stable at about 50% (Fig. 4). However, the environmental conditions for the white-rot fungus were not adequate because no composition of MDF-CFF experienced any decay (Fig. 5). In comparison, when blocks were exposed to the brown-rot fungus (*Gleophyllum trabeum*) for the same 12-week exposure, a

distinct reduction in final moisture content corresponded with an increased percentage of CFF (Fig. 4). This reduction in moisture content clearly contributed to a progressive reduction in brown-rot decay as the proportion of CFF increased from 0 to 25% (Fig. 5).

Careful study of Figures 4 and 5 suggests that CFF levels greater than 10% impart enough resistance to water absorption into the 19-mm<sup>3</sup> dry MDF-CFF blocks to result in significantly reduced weight loss in the ASTM D 143 soil-block test. It may be that CFF itself does not impart bioefficacy, but that has not been definitively established. Rather, addition of  $\geq 10\%$  CFF seemed to impart a certain amount of water resistance to conductive-mode moisture absorption as opposed to a vapor or pure water-soak mode of moisture absorption. This reduction in MDF-CFF moisture content in turn seemed to inhibit brown-rot decay in the 12-week ASTM D 143 soil-block test. This same effect was noted in the Phase I results. In that work, CFF-rich composites, particularly those in which the face layers had a higher CFF loading than the core layers, seemed to inhibit subsequent moisture absorption in the ASTM D 143 soil-block test and hence may inhibit apparent decay.

The potential of multi-layered MDF-CFF composites definitely merits further study. We continue to study both the bioefficacy of CFF and the relative benefits of multi-layer composites.

The enhanced resistance of MDF-CFF composites to moisture seems to be a major advantage of these systems. The Phase II results clearly show that MDF-CFF composites can absorb moisture from the air. As an independent material, CFF can be considered as both hydrophilic and hydrophobic. At a molecular level, 39 of 95 amino acids in the keratin monomer (about half) are hydrophilic (Kunio et al. 1986). The most abundant amino acid in CFF keratin is serine, and each surface of serine has a corresponding free -OH. However, because CFF fibers are very fine, at a macroscopic level feather fiber has an inherent morphological problem with liquid-phase wettability. The surface of CFF is too fine to have enough surface force to bend water; water droplets will bead on clean CFF. Moisture can be absorbed through a fine mist. Once fibers are wet, extra force is required to dry the fibers at the hydrophilic sites. It could also be that since PF resin can bind to the most structurally available serine sites, the remaining sites exposed on CFF would be hydrophobic. In future work, we hope to optimize processing of the keratin-resin reaction instead of the wood-resin reaction, and thereby it may be possible to realize an even greater level of moisture resistance and property enhancement in MDF-CFF composites. Fiber to fiber, the keratin in CFF is tougher than cellulose, but cellulose has a higher concentration of -OH binding sites on a mole fraction basis.

## **CONCLUDING REMARKS**

The properties of fiberboard made with different proportions of wood fiber (MDF) and chicken feather fiber (CFF) were evaluated. Initial strength and stiffness of MDF-CFF composites were lower than that of all-wood control panels, but resin chemistry and processing procedures have yet to be optimized. The use of a constant 5% concentration of phenol formaldehyde resin as an adhesive probably does not accurately represent the optimal adhesive concentration, nor does it absolutely reflect the optimal choice of adhesive type. More importantly, even though no wax was used in manufacturing the fiberboard composites, the physical properties of MDF-CFF mixtures showed a marked improvement in resistance to some modes of water absorption compared to control panels made of all wood fiber. The resistance to water absorption effect is probably related to the hydrophobic component amino acids within the keratin of CFF. Further testing is currently being conducted to determine the threshold or thresholds of CFF required to enhance water resistance. We are also studying ways to refine resin-fiber compatibility in the process and the potential of alternative adhesive resin types to optimize the strength properties and water exclusion characteristics of MDF-CFF composites.

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**Table 1. Experimental design of Phase I study**

Aspen fiber (%)	CFF <sup>a</sup> (%)	PF resin (%)	Board structure
95	0	5	Single layer
75	20	5	Single layer
75	20	5	Triple layer, CFF core
75	20	5	Triple layer, CFF faces
47.5	47.5	5	Single layer
0	95	5	Single layer

<sup>a</sup>Chicken feather fiber.

**Table 2. Experimental design of Phase II study**

Aspen fiber (%)	CFF (%)	Resin (%)	Board structure
95	0	5	Single layer
92.5	2.5	5	Single layer
90	5.0	5	Single layer
87.5	7.5	5	Single layer
85	10	5	Single layer
82.5	12.5	5	Single layer
80	15	5	Single layer
75	20	5	Single layer
70	25	5	Single layer



**Table 3. Test specifications for Phase I**

Test	Specimen size (mm)	No. specimens per panel	Reference
Bending (MOE, MOR)	75 by 356	2	ASTM 2003b
Internal bond	50 by 50	4	ASTM 2003b
Decay	19 by 19	4	ASTM 2003a
Water-soak absorption <sup>a</sup>	150 by 150	2	ASTM 2003b
Thickness swell <sup>a</sup>	150 by 150	2	ASTM 2003b

<sup>a</sup>Same specimen was used for water-soak absorption and thickness swell tests.

**Table 4. Mechanical property test results for Phase I<sup>a</sup>**

MDF/CFF/ resin (%)	Board structure	Density (g/cm <sup>3</sup> )	MOE (GPa)	MOR (MPa)	IB (kPa)	TS (%)	WA (%)
95/0/5	Single layer	0.78	2.99	26.6	55	18.9	49.5
75/20/5	Single layer	0.80	2.86	24.0	51	11.0	28.3
75/20/5	Triple layer, CFF core	0.82	3.17	18.8	61	21.6	50.3
75/20/5	Triple layer, CFF faces	0.76	2.17	25.2	72	24.5	55.2
47.5/47.5/5	Single layer	0.78	2.17	21.9	75	7.2	23.9
0/95/5	Single layer	0.74	1.47	16.3	54	5.2	18.0

<sup>a</sup>MOE is modulus of elasticity; MOR, modulus of rupture; IB, internal bond; TS, thickness swell; and WA, water absorption.

**Table 5. Soil-block decay test results for Phase I**

MDF/CFF/resin (%)	Board structure	Weight loss (%)	
		Brown rot	White rot
95/0/5	Single layer	65	47
72/20/5	Single layer	34	32
75/20/5	Triple layer, CFF core	31	43
75/20/5	Triple layer, CFF faces	11	11
47.5/47.5/5	Single layer	6	11
0/95/5	Single layer	16	20

**Table 6. Test specifications for Phase II**

Test	Specimen size (mm)	No. specimens per panel	Reference
Bending (MOE, MOR)	75 by 356	2	ASTM 2003b
Internal bond	50 by 50	4	ASTM 2003b
Decay	19 by 19	2	ASTM 2003a
Water-soak absorption <sup>a</sup>	150 by 150	2	ASTM 2003b
Thickness swell <sup>a</sup>	150 by 150	2	ASTM 2003b
Humidity exposure	50 by 50	1	( <sup>b</sup> )

<sup>a</sup>Same specimen was used for water-soak absorption and thickness swell tests.

<sup>b</sup>No standard reference exists. Test is described in Methods for Phase II.

**Table 7. Mechanical property test results for Phase II<sup>a</sup>**

MDF/CFF/resin (%)	Density (g/cm <sup>3</sup> )	MOE (GPa)	MOR (MPa)	IB (kPa)
95/0/5	0.57	1.73	16.4	233
92.5/2.5/5	0.70	2.24	21.4	314
90/5/5	0.65	2.10	19.2	232
87.5/7.5/5	0.64	1.87	16.6	175
85/10/5	0.66	1.93	13.8	99
82.5/12.5/5	0.61	1.72	11.8	60
80/15/5	0.61	1.63	10.8	50
75/20/5	0.66	1.81	12.7	92
70/25/5	0.64	1.70	8.9	56

<sup>a</sup>All boards were single layer.

**Table 8. Thickness swell and water-soak absorption test results for Phase II<sup>a</sup>**

MDF/CFF/resin (%)	Thickness swell (%)		Water-soak absorption (%)	
	2-h	24-h	2-h	24-h
95/0/5	24	24	103	111
92.5/2.5/5	31	33	91	98
90/5/5	25	28	81	97
87.5/7.5/5	31	33	104	112
85/10/5	37	39	109	118
82.5/12.5/5	39	41	109	118
80/15/5	34	36	103	110
75/20/5	—	35	—	106
70/25/5	40	44	113	122

<sup>a</sup>All boards were single layer.

FIGURES

Figure 1. Test composite panels of aspen fiber and chicken feather fiber (CFF) bonded with phenol formaldehyde (PF) resin.



Figure 2. Pre-pressed mats: (a) single-layer mat showing uniform distribution of aspen fiber; (b) triple-layer mat with aspen fiber on faces and CFF in core.

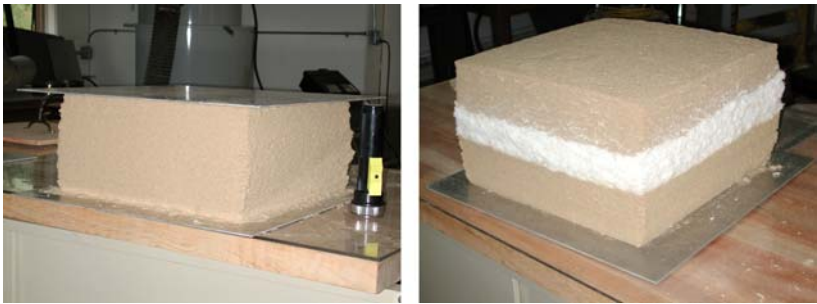


Figure 3. Effect of changing relative humidity (RH) on moisture content of 50- by 50- by 12.5-mm blocks made from various combinations of aspen fiber and CFF. Legend shows percentages of aspen fiber, CFF, and resin in each block.

Figure 3

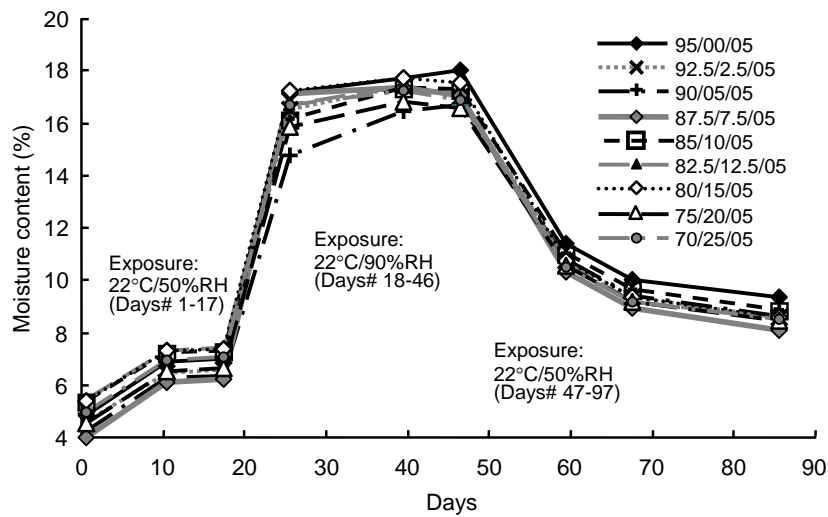




Figure 4. Effect of exposure to decay fungi on moisture content of MDF-CFF composites after 12-week soil-block test.

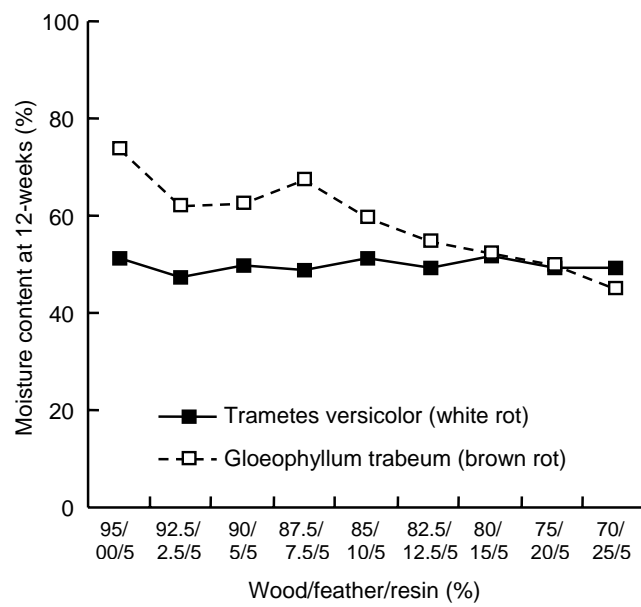


Figure 5. Effect of exposure to decay fungi on weight loss of MDF-CFF composites after 12-week soil-block test.

